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Hybrid Materials Characterization Using Polymer Blends

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ABSTRACT

This paper investigates the effect of blending epoxy and reactive polyester on the mechanical properties on the ensuing laminate in different percent by weight. The laminate with hybrid polymer were tested using ASTM standards for tension, compression, interlaminar shear strength, impact, hardness, fracture toughness and rheological properties which are evaluated as a function of the blending. From the results it was observed that there was an improvement in the strength and fracture toughness. The blended polymer composites containing three different ratios of epoxy: polyester at 50: 50, 60: 40 and 40: 60 by weight. The blend containing 40 wt.% of polyester and 60 wt.% of epoxy showed enhanced tensile adhesive strength, impact strength, hardness and enhanced fracture toughness in comparison to the unmodified samples exhibiting a synergic effect.

Keywords

polymer blends, mechanical properties, fracture toughness, viscosity

INTRODUCTION

Presently, there has been rapid a growth in the development of polymer blends and their end use applications. These applications associated with lower cost with improved properties have spurred more research activities on polyblends. Epoxies are brittle in nature and modification of Epoxy to offset the brittleness was the objective of several researchers. Epoxy resin was modified with epoxidized natural rubber in various percent, it was found that impact resistance can be improved by this blending [1], while the tensile and the shear strength decreased. A two-phase blend with the combination of elastomer modified epoxy and polycarbonate and a three-phase system of elastomer modified epoxy, dyglycidyl ether of bisphenol A and polycarbonate system was studied by the researcher [2]. They found that the both tensile strength and the elongation improved in the both the cases, while with the addition of polycarbonate the tensile strength improved in proportion to the variation of polycarbonate. A review work was conducted on the modification of Epoxy for industrial application and summarized the results [3]. Epoxy was modified with polycarbonate was polymerized with the curing agent.

The author had extensively studied the cure kinetics of the blend using DSC and found out that the increasing polycarbonate had little effect on the cure kinetic of the blend [4]. The enhancement of the fracture toughness of the polymers was studied by the researcher [5]. Another researcher studies the ways and means to enhance the fracture toughness of the laminates [7]. A through review was conducted on the toughening mechanism to offset the brittleness of the epoxy [8]. A study was conducted on enhancing fracture toughness of the fibrous composites [11]. The effect of toughening epoxy with polycarbonate on the flexural properties by impregnating the resin with bamboo fiber [12]. Comparison of flexural strength of different PMMA based blends [13]. A study based on blending rubber toughened polypropylene and polystyrene with acrylonitrile content on the viscoelastic properties [14]. Another study was conducted to improve the impact strength of blend comprising of polypropylene and polystyrene.[16]. An attempt was made to study the properties and the structure of polycarbonate modified epoxy through two different blending processes [18]. The blending of the epoxy with polycarbonate and exploration of the mechanical properties was made in another study [19].

In view of the foregoing discussion, we propose:

1. To develop a hybrid laminate, by blending two different resins: Ly566(Epoxy resin) and reactive polyester resin in the ratio of 50: 50, 60:40 and 40: 60

2. To characterize the resulting laminate in Tension, compression, interlaminar shear, Impact, Mode-I fracture toughness, hardness and viscosity of the resulting blends and study its ensuing properties by comparing the data with unmodified samples.
3. All the mechanical characterization were carried out according to ASTM standards and in ambient conditions

MATERIALS AND METHODS

The following materials were used diglycidyl ether of bisphenol A: Araldite 260 GY, Mw=381 g/mol from Ciba-Geigy; crosslinking agent: Aradur 460, (Ciba-Geigy-HY951). Polyester: Desmophen 1200 slightly branched polyester with 5% OH from Bayer. The hardener, usually MEKP (Methyl Ethyl Ketone Peroxide) to aid the curing process, Cobalt Octoate with 6% Cobalt content is an effective accelerator for polyester. It affects curing or polymerization of Unsaturated Polyester Resins in combination with catalyst likes MEKP (Methyl Ethyl Ketone Peroxide) being used even as a single Drier. A 250-gsm glass fabric was used as reinforcement obtained from M/S Javanthee Enterprises Chennai.

Blending

The epoxy resin and polyester resin were blended with three different ratios of 50: 50, 60:40 and 40:60 by weight. Bisphenol was slightly heated in beaker to a temperature of 40^{o} C to reduce its viscosity while the polyester resin was gently infused while constantly stirred using magnetic stirrer. The required cross liking agents were used. This stirring was continued for an hour and then laminate was cast using wet lay-up technique, A woven mat was initially cut down to a size and a coat of the blend was applied on the open aluminium mould. Care was taken to release the part from the mould by applying appropriate release agents. The hybrid laminate was tested for its mechanical strength. The fabricated blended samples can be referred in figure 1

E:P::50:50 E:P::60:40 E:P::40:60

Figure 1. Blended specimens

The following tests were conducted to functionalize the hybrid laminates: tension test (ASTM D3039) shown in figure 2, Compression test (ASTM D 5413) as in figure 3, Shear Test (Inter Laminar shear- ASTM D2344) refer to figure 4, Fracture Toughness (ASTM D6671) can be noted in figure 5, while Impact Test (ASTM D256) samples are referred to in figure 6, Hardness Test and Viscosity.

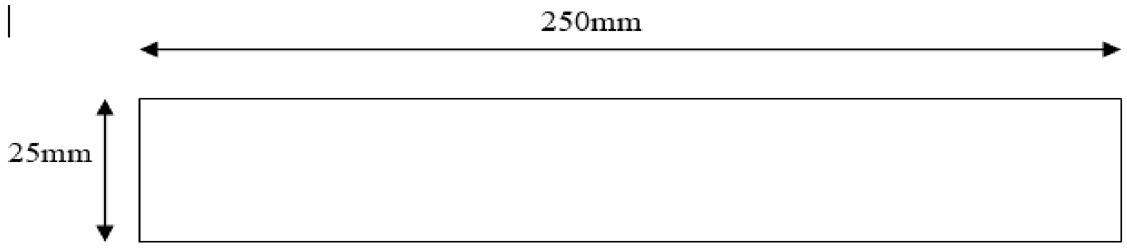

Figure 2. Line diagram of the tensile specimen

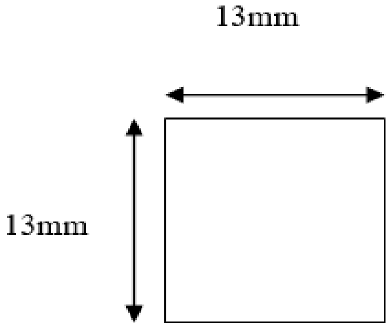

Figure 3. Schematic of compression specimen

Figure 4. Interlaminar shear test sample

Figure 5. Fracture toughness specimen- A DCB specimen

Figure 6. Impact test specimen

Sample Fabrication

After the blended polymer was obtained, the samples were fabricated using the wet-layup technique according to ASTM standards. A unidirectional 250 GSM stitched woven mat was used as the reinforcement with the blended polymer. A total of 5 samples were cast for each test evaluation. The blend was taken in proper ratios to assist in polymerization process. The laminate was laid on Aluminum mould for twenty-four hours for the polymerization to set in, while appropriate release agents were applied on the mould to facilitate easy removal of the part. Post curing was not attempted. Once the laminate was demolded the test specimens were machined to the specific test needs.

Testing

A 40 kN universal test machine was used to categorize Tensile test, compression. Shear, and Fracture toughness test. In all cases the crosshead was kept at constant rate of 5 mm/min. Rockwell equipment for hardness test, Charpy test method for the impact testing. While Reed wood viscometer was used to estimate the viscosity of the blend. For consistency all the tests were repeated three times and average values were reported.

RESULTS AND DISCUSSION

Tension Test

A total of 9 samples were fabricated and were tested in 40 kn UTM in the various ratios of the polymer blends. The crosshead was set at 5mm/min and the load the break was noted. In Tensile test results, the unmodified Glass fiber reinforced with epoxy laminate has good ultimate tensile strength than other laminates. In Fiber reinforced with blended resin laminates the ratio of epoxy: polyester at 60:40 had good ultimate tensile strength than with the other blended resin laminates combinations. The modified laminate with 50:50 combination had lower Ultimate tensile strength than other fiber reinforced with blended resin laminates. So, Fiber reinforced with blended resin cross ply laminates did not show an improvement on tensile Strength and tensile young's modulus. While glass fiber reinforced with blended resin ratio (50:50 and 60:40) laminates have good improvement on ultimate tensile strength. And results are presented in table 1. The failure of the sample is shown in figure 7. The stress strain diagram for different compositions is referred in figure 8. While figure 9 illustrates the specific strength of the samples. Figure 10 may be referred for specific tensile strength results

Table 1. Tensile Test Results

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40: 60
Displacement(mm)	10	10	8	8	8.5
Maximum extension(mm)	0.148	0.702	0.284	0.195	0.283
Tensile strength (MPa)	234	179	172	187	151

Figure 7. Tested tensile Sample

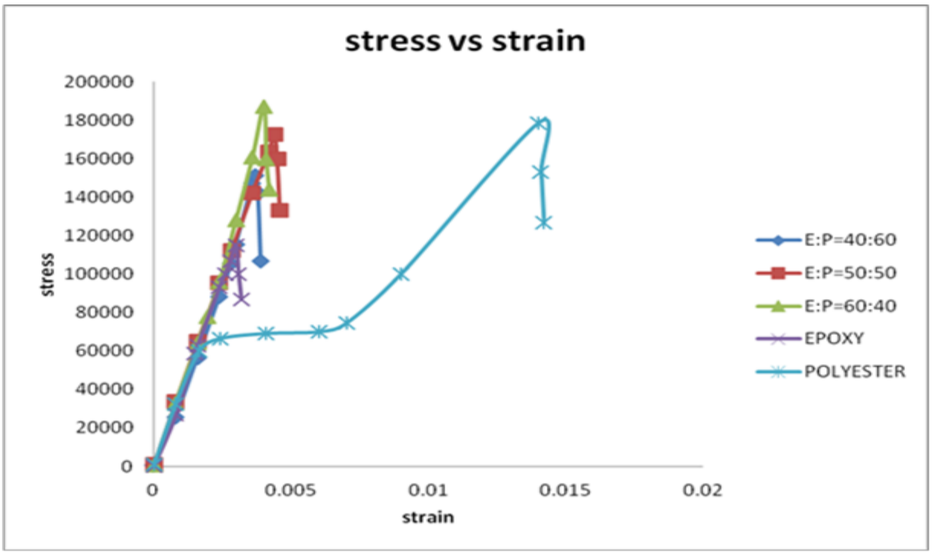

Figure 8. Stress VS. Strain Graph for different ratios

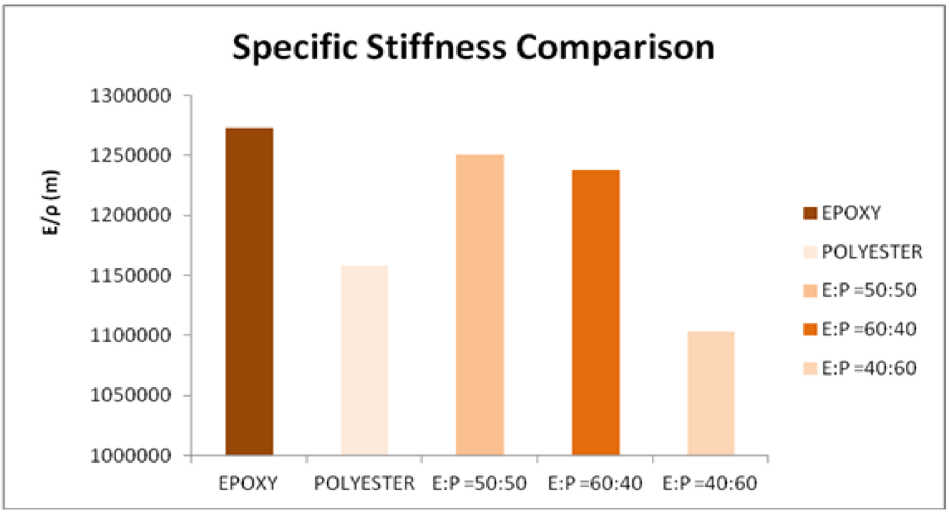

Figure 9. Specific Stiffness comparison

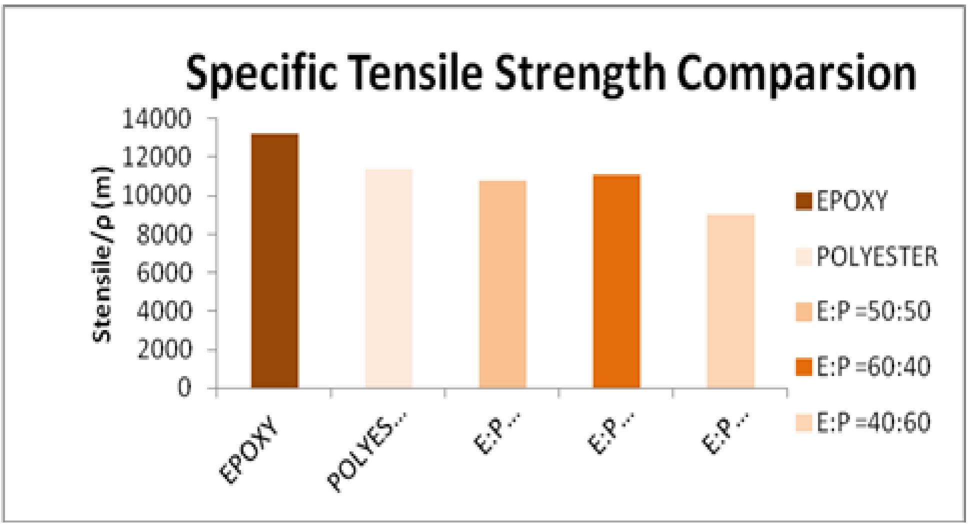

Figure 10. Specific tensile strength Comparison

Compression Test

Specimens are placed in between the fixed and movable jaws or flanges of the testing machine. To avoid inaccuracies, the specimen must be aligned along the axis and apply the loads the specimen until specimen fails. Then the values of compressive or breaking load and compressive strength of each specimen were recorded, and the tests were repeated for five samples. Failed compressive samples are presented in figure 11

Figure 11. Failed Sample

Table 2. Compression Test Results

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40:60
Displacement(mm)	1.69	2.3	2.8	3.9	7.54
Breaking load (kN)	45.64	52.10	49.84	50.74	36.4
Compressive strength (MPa)	270	308	295	300	215

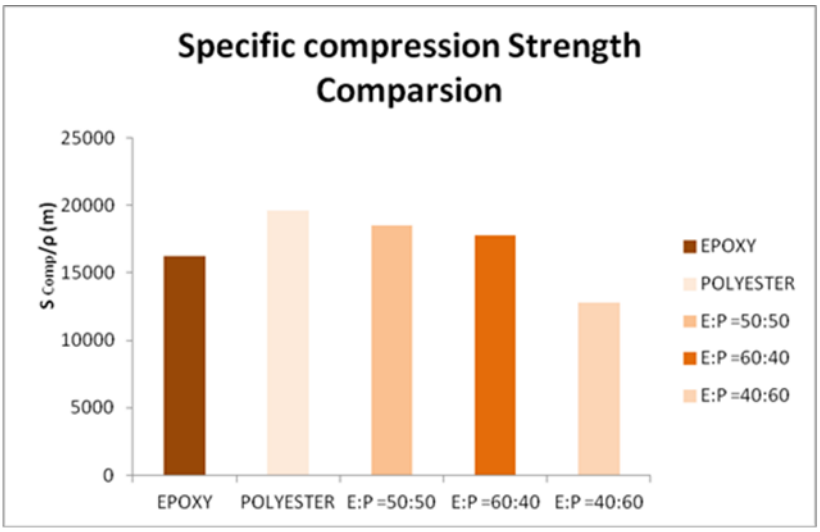

Figure 12. Specific Compression strength

In compression test glass fibre reinforced with epoxy had good ultimate compressive strength than other laminates. On reinforcement with blended resin the laminates of the ratio 60:40 exhibited better ultimate compressive strength than the other blended resin laminates. At 40:60 ratio the laminate had lower ultimate compressive strength. The experimental results are presented in table 2, while figure 12 refers to the comparison of the compressive strength.

Shear Test

Load the sample into the extensometer's top clamp. To avoid inaccuracies in the result, the sample must be aligned vertically with the top and bottom clamps when the torque is applied. Program the "strain rate" at which the extensometer will pull the sample item apart. Run the extensometer until your sample material breaks. Observe the results from the extensometer. The machine will produce a stress-versus-strain curve that measures elasticity and force. The slope of the line represents the "modulus of elasticity". Measure the distance between the marks to determine the length of elongation in the sample. Figure 13 illustrates interlaminar shear specimen and figure 14 represents the array of failed samples.

Figure 13. Interlaminar shear strength Specimen

Table 3. Shear test results

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40: 60
Displacement (mm)	4.1	4.6	5	5.4	4.8
Breaking load (kN)	2	2.04	1.9	1.86	1.52
Shear strength (MPa)	0.009	0.009	0.0112	0.008	0.021

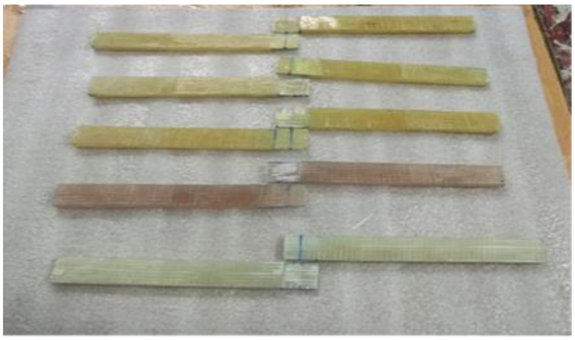

Figure 14. Tested Samples

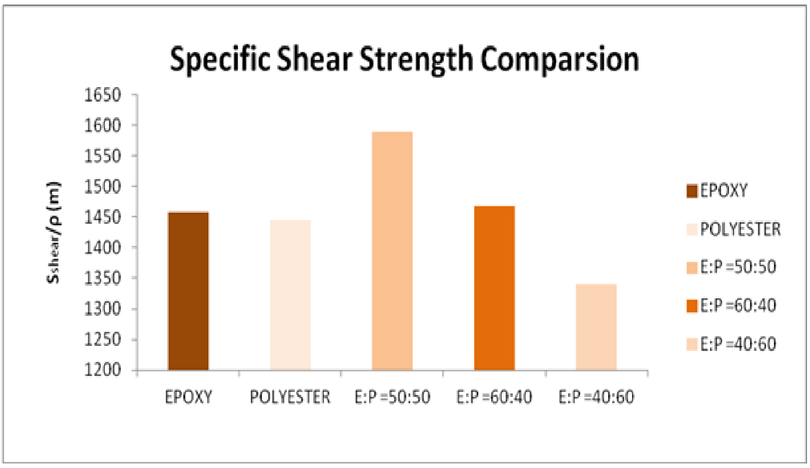

Figure 15. Specific Shear strength Comparison

Shear test results revealed that epoxy reinforced with glass fiber(unmodified) exhibited better shear strength than other unmodified laminates. With the blended resin at 50:50 ratio had good Ultimate shear strength than other modified laminates samples. With the blended resin ratio of 40:60, the laminate has lower ultimate Shear strength than the other ratios of blended resin laminates. Shear strength of these laminates are approximately at the same level. In fibre reinforced with blended resin laminates at the ratios of 50:50 and 60:40 performed better. The results are presented in table 3. The failed samples are referred in figure 14. The comparison of specific shear strength data is referred in figure 15.

Impact test

Impact load is produced by swinging of an impact weight (hammer) from a height. Release of the weight from the height swings the weight through arc of a circle, which strikes the specimen to fracture at the notch. According to ASTM D256 impact test was implemented. Specimen is clamped to act as vertical cantilever beam with the notch on tension side. The impacted samples are shown in figure 16 with different blending ratios.

a. Polyester

b. Epoxy

c. E:P::40:60

d. E:P::60:40

e. E:P::40:60

Figure 16. Impacted test samples at different blending ratios

Table 4. Impact Test Results

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40;60
Impact strength (Nm/mm2)	0.55	0.53	0.77	1.25	0.89

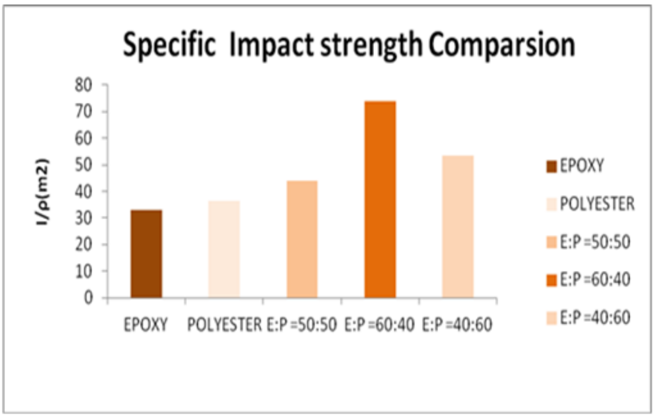

Figure 17. Specific Impact Strength Comparison

In impact strength test results are presented in table 4. Noting that the 60: 40 ratios had better impact strength than the other samples with ratios of hybrid resins. Figure 17 refers to the comparison of the impact strength.

Fracture Toughness Test

To assess the resistance of the laminate against crack growth a double cantilever beam was fabricated according to ASTM standards. The initial pre-cracking was induced by jeweller's saw, Piano hinges (actually the hinges were obtained from door padlocks) were attached to facilitate the ease of loading. The cross-head speed was set at 5mm/min with constant displacement and at ambient conditions on a 40kN UTM. A compliance calibration method was used as the data reduction scheme. The double cantilever beam specimen with attached hinges for facilitating load application shown in figure 18.

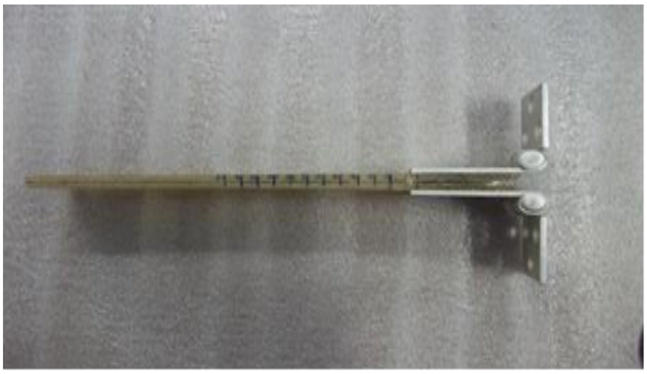

Figure 18. Double cantilever beam- Fracture toughness test sample.

Table 5. Fracture Toughness

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40;60
Fracture toughness (J/m2)	2.09 e-02	8.44e-03	1.47e-02	2.08e-02	1.55e-20

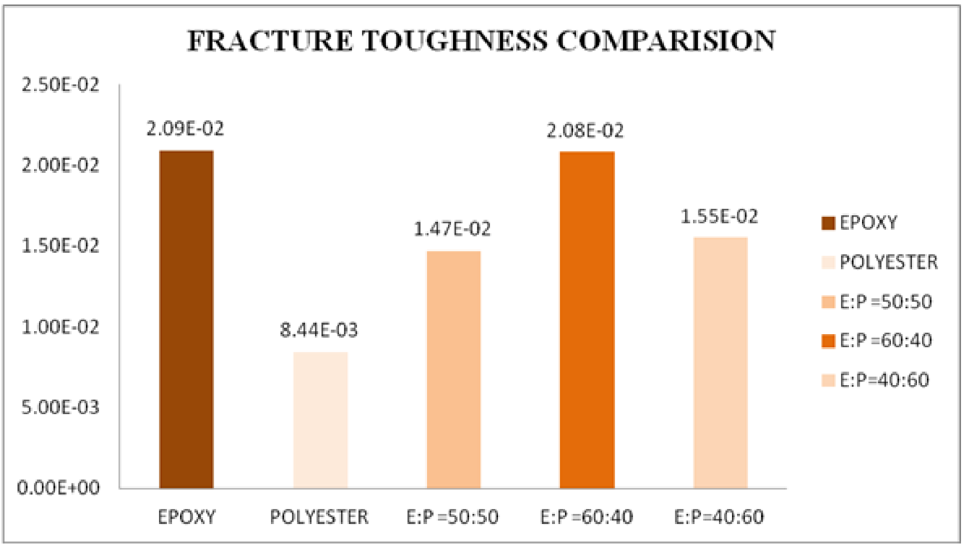

Figure 19. Fracture Toughness comparison

Figure 20. Failed DCB Sample

Glass fiber reinforced with these polymers had low value fracture toughness than other fiber laminates. With the blended resin, fracture toughness t with the combination of the blend 60:40 was higher than other blended resin samples. In fracture toughness of blended laminates did not considerable improvement on comparison with unmodified samples. Test data is presented in table 5. The comparison of strain energy release rates is shown in figure 19, while figure 20 refers to failed DCB sample. It may be noted that a starter crack was generated with a jeweller's saw for a length of 25 mm.

Hardness Test

The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released, and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number. Test results are presented in table 6, while the figure 21 illustrates the comparison. The 40:60 blend had better hardness on comparison., while the least was 60: 40 blends.

Table 6. Hardness test results

Properties	Epoxy	Polyester	Epoxy: Polyester		
			50:50	60: 40	40;60
Hardness (RHN)	54	57	73	35	82

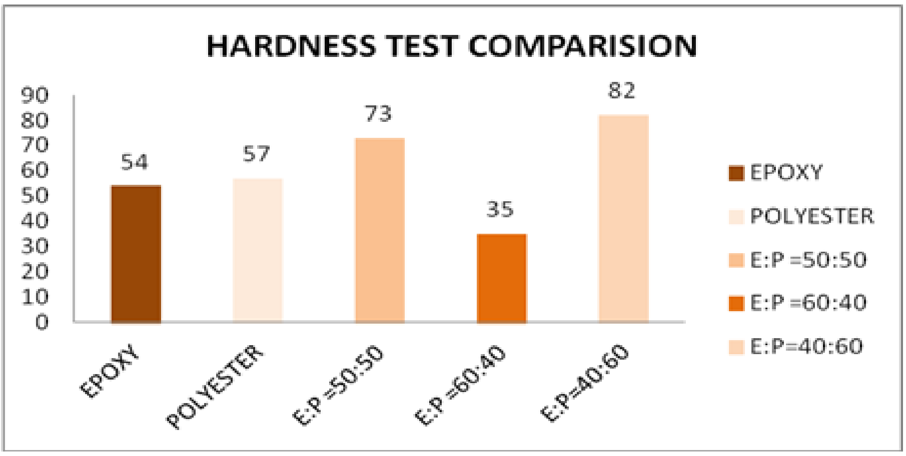

Figure 21. Comparison of Hardness

In hardness test results, glass fiber reinforced with blending resin have good improvement on hardness of material. Cross ply laminates, hardness of Epoxy Polyester (60:40) had higher hardness than other laminates.

Viscosity Tests

The redwood viscometer consists of vertical cylindrical oil cup with an orifice in the centre of its base. The orifice can be closed by a ball. A hook pointing upward serves as a guide mark for filling the oil. The cylindrical cup is surrounded by the water bath. The water bath maintains the temperature of the oil to be tested at constant temperature. The oil is heated by heating the water bath by means of an immersed electric heater in the water bath, the provision is made for stirring the water, to maintain the uniform temperature in the water bath and to place the thermometer it records the temperature of oil and water bath. The cylinder is 47.625mm in diameter and 88.90mm deep. The orifice is 1.70mm in diameter and 12mm in length, this viscometer is used to determine the kinematic viscosity of the oil. From the kinematic viscosity the dynamic viscosity is determined. Test data is presented in table 7, while in table 8, 9, 10 and 11 refers to test data for the various blends. As expected, the ratio 60: 40 samples fared better. While figure 22 compares the viscosity of the blends.

Table 7. Epoxy- resin viscosity properties

Sl. No	Temperature (^{o} C)	Density (Kg/m^3)	Time (sec)	Kinematic Viscosity (Stokes)	Dynamic Viscosity (Poise)
1	25	1280	1500	3.9000	5.00
2	32.5	1279.95	1300	3.8900	4.900
3	80	1279.64	210	0.5375	0.688
4	90	1279.37	110	0.2700	0.350

Table 8. Polyester-resin viscosity properties

Sl. No	Temperature (^{o} C)	Density (Kg/m^3)	Time (sec)	Kinematic Viscosity (Stokes)	Dynamic Viscosity (Poise)
1	25	1130	22000	5.300	6.00
2	32	1129.95	18250	4.75	5.35
3	80	1129.64	800	2.078	0.20
4	90	1129.57	700	1.818	0.18

Table 9. Epoxy Polyester (50:50) Resin Viscosity Properties

Sl. No	Temperature (^{O} C)	Density (Kg/m^3)	Time (Sec}	Kinematic viscosity (Stokes)	Dynamic Viscosity (Poise)
1	25	1210.00	1600	4.6	5.6
2	32	1209.94	1265	4.54	5.55
3	72.5	1209.69	590	1.531	1.8
4	82.5	1209.62	340	0.878	1.063
5	88	1209.54	250	0.643	0.77

Table 10. Epoxy Polyester (60:40) Resin Viscosity Properties

Sl. No	Temperature (^{O} C)	Density (Kg/m^3)	Time (Sec}	Kinematic viscosity (Stokes)	Dynamic Viscosity (Poise)
1	25	1220	1375	4.40	5.4
2	32	1219.49	1165	4.10	5.0
3	80	12.19.64	240	0.564	0.75
4	85	1219.61	230	0.890	0.719
5	88	1219.59	220	0.564	0.687

Table 11. Epoxy Polyester (40:60) Resin Viscosity Properties

Sl. No	Temperature (^{O} C)	Density (Kg/m^3)	Time (Sec}	Kinematic viscosity (Stokes)	Dynamic Viscosity (Poise)
1	25	2290	1937	5.46	6.5
2	32	1189.98	1190	4.76	5.6
3	70	1189.74	460	1.192	1.4
4	80	1189.66	320	0.827	0.98
5	90	1189.57	190	0.484	0.576

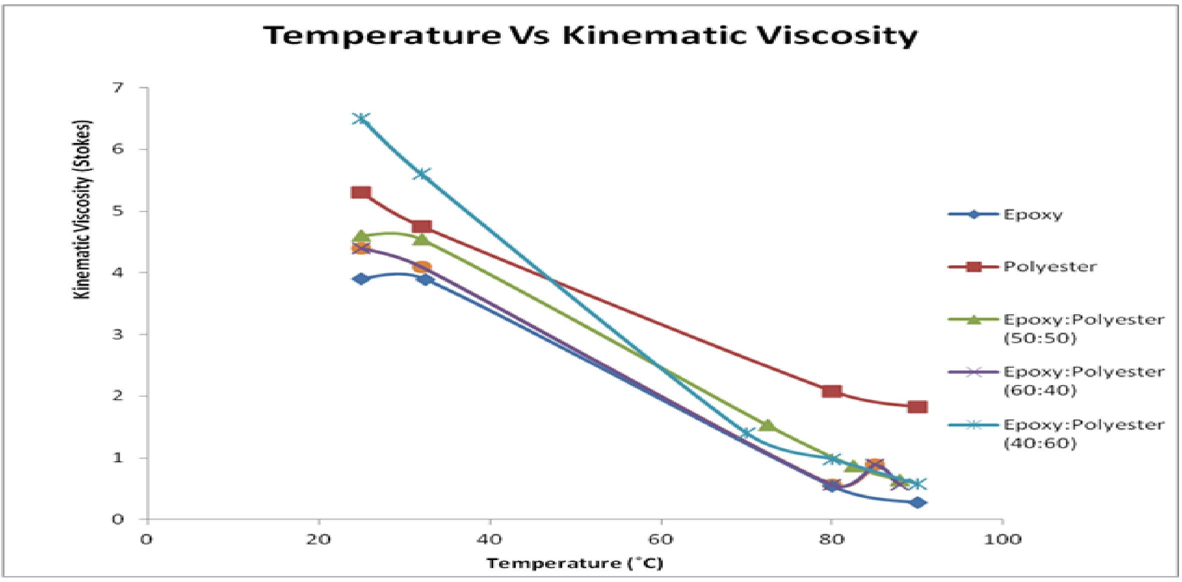

Figure 22. Temperature vs Kinematic Viscosity

CONCLUSION

The primary goal of this work was to identify the improvement on the mechanical properties of composite laminate obtained by blending two polymer resins namely: epoxy and polyester. Both mechanical (Tensile, compression, interlaminar shear, fracture toughness, impact and hardness) as well as rheological tests were conducted, which were necessary to assess a new material ensuing out the polymer blends. All the samples pertaining to the characterization were cast by wet layup technique, in strict adherence to ASTM standards. The blending ratio of the two polymers was chosen for this study were: 50:50, 60: 40 and 40: 60 by weight. Neither the blending nor the casting technique offered little difficulties. The properties of laminate reinforced with un modified polymers and modified polymer blends were evaluated and compared. On the basis of above the experimental results, it was found that glass fibre reinforced with blended resin exhibited superior impact strength and hardness than that of the unmodified test samples.

The laminate casted from blended resin performed better in tensile, compressive and shear strength and as expected the results appeared closer to unmodified laminates. The fracture toughness tests results were better for the 60: 40 combinations of the polymer blend, while the others did not fare batter and least was that of unmodified polyester resin. As temperature increases the viscosity of the polymer do decrease and as expected the 60: 40 had better at moderate temperatures. The motive for this research was the basis for the development of composite material by blending two different resins for structural application. To conclude that the performance of the laminates cast by the blended polymers showed promise and may have scope in application of aerospace structure industry with relatively to moderate load bearing members, and more so in the other industries.

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CONFLICT OF INTEREST

The author states that there was no conflict of interest.

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